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# APPLICATION OF ERTS-A IMAGERY TO FRACTURE RELATED MINE SAFETY HAZARDS IN THE COAL MINING INDUSTRY

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## SIGNIFICANT RESULTS

### APPLICATION OF ERTS-1 IMAGERY TO FRACTURE RELATED MINE SAFETY HAZARDS IN THE COAL MINING INDUSTRY

Charles E. Wier and Frank J. Wobber  
Bloomington, Indiana and Washington, D. C.

The authors have identified the following significant results. The most important result of the study to date is the demonstration of the special value of repetitive ERTS-1 multiband coverage for detecting previously unknown fracture lineaments despite the presence of a deep glacial overburden. The Illinois Basin is largely covered with glacial drift and few rock outcrops are present. Most of the limited knowledge of the structure in the area has been derived from mining, drilling and geophysical surveys. General structural trends were known at the time of ERTS-1 launch but the presence of pronounced major fracture systems in the central part of the basin was unsuspected. A contribution to the geological understanding Illinois and Indiana has been made. This data may not only contribute to improved mine safety but have economic significance in some areas of southeast Illinois. High-altitude color infrared photography at 1:120,000 scale is also providing significant fracture data in the glacial drift covered areas. Preliminary analysis suggests a tentative correlation between ERTS/aircraft identified fractures and mine fatalities.

Analysis of ERTS imagery has provided useful information to the State of Indiana concerning surface mined lands. The contrast between healthy vegetation and bare ground as imaged by Band 7 is sharp and substantial detail can be obtained concerning the extent of disturbed lands, associated water bodies, large haul roads and extent of mined lands revegetation. During the growing season, bare ground is readily identifiable and changes in mine configuration of only a few acres can be made. The repetitive image acquisition capability of ERTS makes a national mined lands surface-mining monitoring program a distinct possibility.

The feasibility of acquiring fracture data under difficult physical conditions i.e. in areas of intense agriculture and deep glacial drift has been demonstrated and will benefit geological studies nationally. The likelihood of applying ERTS derived fracture data to improve coal mine safety in the entire Illinois Basin is suggested from studies conducted in Indiana.

**Details of Illustrations in  
this document may be better  
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<p>16. Abstract This ERTS-1 experiment is to evaluate the application of ERTS-1 imagery and complementary high altitude aircraft photography to geological fracture detection in glacial drift-covered areas, and to relate the location of these fractures to areas of past and future mining hazards.</p> <p>Analysis of the ERTS-1 imagery and high-altitude color infrared photography indicates that useful fracture data can be obtained in the Eastern Interior Coal Basin despite a glacial till cover. ERTS MSS bands 5 and 7 have proven most useful for fracture mapping in this region.</p> <p>Preliminary results of the analysis suggest a reasonable correlation between image-detected fractures and mine roof fall accidents for a few areas investigated. ERTS applications to surface mining operations appears probable, but further investigations are required.</p> <p>Information relating to surface mined areas has been derived from the analysis of the ERTS imagery. These data include areal extent of mining, general estimates of vegetal cover, distribution and areal extent of mining-produced water bodies and differentiation between deciduous and evergreen reforestation.</p>					
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## PREFACE

The objective of this ERTS-1 experiment is to evaluate the application of ERTS-1 imagery and complementary high altitude aircraft photography to geological fracture detection in glacial drift-covered areas, and to relate the location of these fractures to areas of past and future mining hazards.

Analysis of the ERTS-1 imagery indicates that useful fracture data can be obtained in the Eastern Interior Coal Basin despite a glacial till cover. This was established early in the program following intensive analysis of high altitude color infrared photography acquired by NASA in the 1971 Corn Blight studies, and confirmed with receipt of ERTS-1 imagery. ERTS MSS bands 5 and 7 have proven most useful for fracture mapping in this region.

Preliminary results of ERTS and aircraft imagery analysis suggest a reasonable correlation between image-detected fractures and mine roof fall accidents for a few areas. Fracture information acquired from ERTS (and complementary aircraft) can be successfully applied to areas of future mining to assist in reducing the potentially disastrous and economic effects of roof falls in underground mines. A contribution of ERTS to surface mining operations appears probable, but further investigations are required.

Considerable information relating to surface mined areas has been derived following manual analysis of the ERTS and NASA aircraft imagery. These data include:

- Areal extent of mined area
- General estimates of vegetal cover
- Distribution and areal extent of mining-produced water bodies
- Differentiation between deciduous and evergreen reforestation

Analysis related to mining and the environment is continuing and the information acquired has proven of value to the State and the Coal Industry. A 1:250,000 scale ERTS-surface mining photo-map series is being prepared from ERTS-1 imagery and may serve as a prototype to other states.

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## Type II Report

### APPLICATION OF ERTS-A IMAGERY TO FRACTURE RELATED MINE SAFETY HAZARDS IN THE COAL MINING INDUSTRY

#### 1.0 INTRODUCTION

Mine safety in coal mining has received significant public attention because roof falls in underground mines often result in loss of life. Less commonly publicized are rockfalls, blasting accidents and occasional flooding which constitute hazards in surface mines.

Roof falls and rock bursts may account for only one or two fatalities in any underground mine throughout its history, but the occurrence rate of such potentially deadly accidents is high. Roof failure in underground mines is often associated with zones of weakness produced by some combination of mining activity and natural fractures (joints and faults) in and near the coal seam(s) being mined. Furthermore, structural weakness associated with mining causes rock falls and requires modifications in mining (drift) direction which are costly to the industry. Blasting accidents in surface mines may also be aggravated by the presence of fracture zones.

In most cases, information related to the presence of fractures is difficult to acquire unless closely spaced core drilling is conducted. And then, information concerning fracture orientation can be determined only by acquiring oriented cores. Useful fracture data can be acquired from aerial remote sensing records, but such records are not routinely used by the mining industry for fracture mapping in coal-producing areas. Equally significant, the discrimination of fractures in areas with thick overburden has not been widely investigated, and the opportunity provided by repetitive aerial and/or orbital coverage to detect subtle (surface) fracture traces indicative of deeply buried bedrock fractures has not been fully explored.

NASA's ERTS-1 program provided an opportunity to acquire repetitive synoptic coverage to develop fracture mapping techniques in areas obscured by thick overburden, to rapidly acquire such data in an area of active surface and underground coal mining, and to distribute these data to interested groups. Figure 1 is an index map of the test area selected for the investigation.



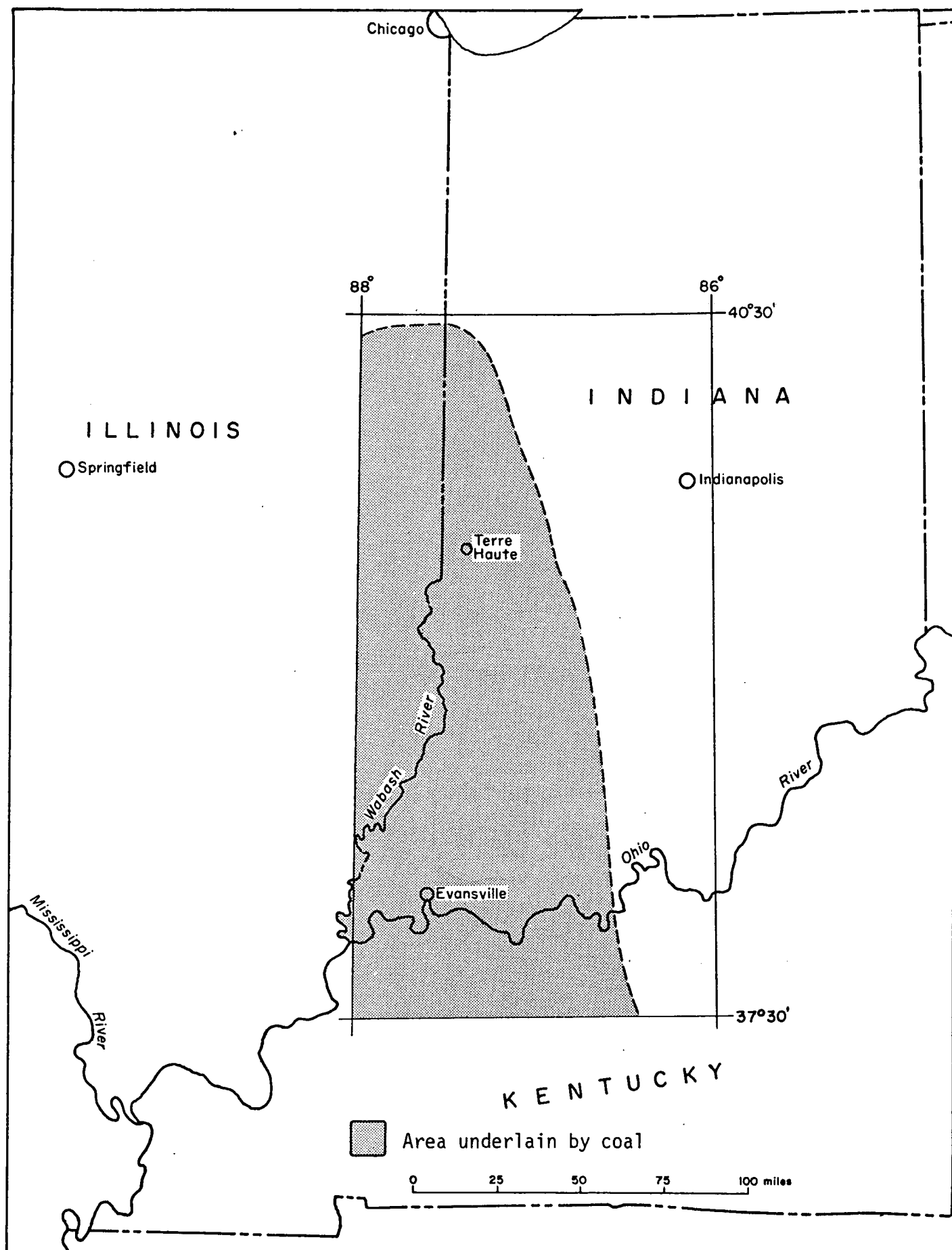


Figure 1. Map of Indiana and parts of Illinois and Kentucky showing the MMC #325 Test Area.

This report documents the scientific and technical progress and significant results for the previous six months of contract No. NAS5-21795, "Application of ERTS-A Imagery to Fracture-Related Mine Safety Hazards in the Coal Mining Industry."

Principal activities completed during the preceeding six months include:

- Compilation of coal mining accident data in Indiana
- Assembly of underground coal mine configuration maps
- Intensive fracture analysis of ERTS-1 imagery ( and validation procedures)
- Assessment of ERTS-1 imagery utility by spectral band
- Updated mined land inventory using ERTS imagery
- Preparation of 1:250,000 scale photomaps from ERTS-1 imagery (continuing)
- Field program of fracture measurement (continuing)
- Fracture mapping using 1:120,000 scale color infrared photography, and low altitude color and color infrared photography and radar imagery
- Preparation of a Data Analysis Plan

The status of each principal task completed as part of the investigation can be referenced in Appendix D.

## 2.0 BACKGROUND

### 2.1 Literature Review

A literature search has been completed and articles relating to fracture analysis, especially those which describe fracture analysis in areas with surficial materials have been identified and studies. Appendix B is an annotated bibliography of articles searched. Maps and reports relating to the geology, and operating surface and underground mines within the test area (Figure 1) have also been assembled.

### 2.2 Mine Accident Data

A statistical compilation of coal mine accident data and areas of serious mine subsidence has been made by the Indiana Geological Survey. These data have been summarized on 1:250,000 scale maps to pinpoint high accident areas. Mine accident data will be correlated with fractures identified using aerial and orbital imagery.

### 2.3 Mine Configuration Data

Configurations of underground mines are being evaluated for indications of roof instability and this information is being compared with areas of known surface subsidence over active and inactive mines. These data are being plotted on 1:250,000 scale maps and compared to fracture data derived from ERTS and high altitude aircraft imagery.

## 2.4 Geological Data

### 2.4.1 Geomorphology

Three basic geomorphic regions are included in the test area; these are the southern unglaciated area, the central belt of Illinoian-age glacial drift, and the northern region of Wisconsin-age drift. Each of these regions is being evaluated for the relative abundance of fractures and other geologic features which can be seen on aerial and satellite imagery, i.e. under varying physical conditions of glacial deposition.

### 2.4.2 Glacial Drift Cover

Data concerning glacial deposits have been assembled to estimate variations in the thickness of glacial deposits across the test area. The 1:250,000 scale surface geologic map sheets<sup>1/</sup> classifies glacial deposits and shows land modified by surface mining as a separate geologic unit.

### 2.4.3 Geological Structure

Structural maps, geological cross-sections, and related reports have been studied by EarthSat's imagery analysts as important background information for the interpretation of fractures and fracture patterns. Major structural features have been identified on the imagery including the major outcrop belts of the Illinois basin strata and portions of the Mt. Carmel fault trace near Bloomington, Indiana. A map of faults in the test areas has been prepared.

## 2.5 Field Activities

In August 1972, Indiana Geological Survey (IGS) and Indiana Coal Association personnel were briefed by EarthSat concerning the utility of small scale imagery in geological and environmental studies. Field investigations were also conducted by IGS and EarthSat personnel to assess the problems of acquiring fracture data in the field. The test area contains relatively few surface exposures other than highwalls associated with surface mining.

Field measurements of the strike and dip of joints in the bedrock exposed by coal mining are being made by the Indiana Geological Survey on a continuing basis. These data will be incorporated into a fracture map for the Indiana portion of the Eastern Interior Coal Basin and will serve to verify specific fracture traces identified from ERTS-1 imagery by EarthSat. Fracture measurements are also being obtained by IGS from underground mines.

---

<sup>1/</sup>

The Vincennes sheet (Gray, H.H., Wayne, W.J., and Wier, C.E., Geologic Map of the 1° x 2° Vincennes Quadrangle and Parts of Adjoining Quadrangles. Indiana Geological Survey, 1970) served as a base for an ERTS-1 Mined Land Inventory map.

In association with field work related to fracture trace mapping, field checking of mined land inventory maps was conducted. A seminar describing the ERTS Program and the Indiana Mine Safety experiment was held in Booneville, Indiana for state and federal personnel involved in coal mining and land reclamation.

## 2.6 Theories for Fracture Manifestation in Glaciated Areas.

Occasionally, fractures traces<sup>1/</sup> identified from aerial or orbital images can be traced directly to rock outcrops or surface mine highwalls. It is, however, difficult to explain the mechanisms by which fracture traces are expressed through a cover of unconsolidated drift material that is sometimes several hundreds feet thick. Mollard<sup>2/</sup> discussed the causes for fracture trace development in glaciated regions, and suggested that there are two basic mechanisms for fracture development:

- (1) An oscillatory or rhythmic mechanism caused by short-duration stresses in which the earth's crust behaves like an elastic material with a definite strength limit; and
- (2) A non-oscillatory deep-seated tectonic mechanism induced by long-duration stresses to which the earth's crust behaves like a plastic material with a yield point.

The first mechanism results mainly from earth tides and is most responsible for maintaining existing fracture traces through thick unconsolidated cover. The second mechanism is related to continental isostatic adjustment and is similar to the stress buildups associated with earthquakes, though of smaller magnitude. Once a break has been established within the glacial cover, the fracture trace is accentuated and deepened by long-continued leaching and settlement of the overburden which eventually causes slight surface depressions. (Figure 2). These subtle depressions may in turn be accentuated by surface runoff. Differences in microrelief and soil permeability localize soil moisture and therefore accelerate vegetal growth. Both of these phenomenon may expressed by variations in image tone.

---

<sup>1/</sup> Linear surface expressions of what are judged to be bedrock fractures at depth

<sup>2/</sup> Mollard, J.D., Aerial Mosaics Reveal Fracture Patterns on surface materials in southern Saskatchewan and Manitoba. Oil in Canada, August 5, 1957.

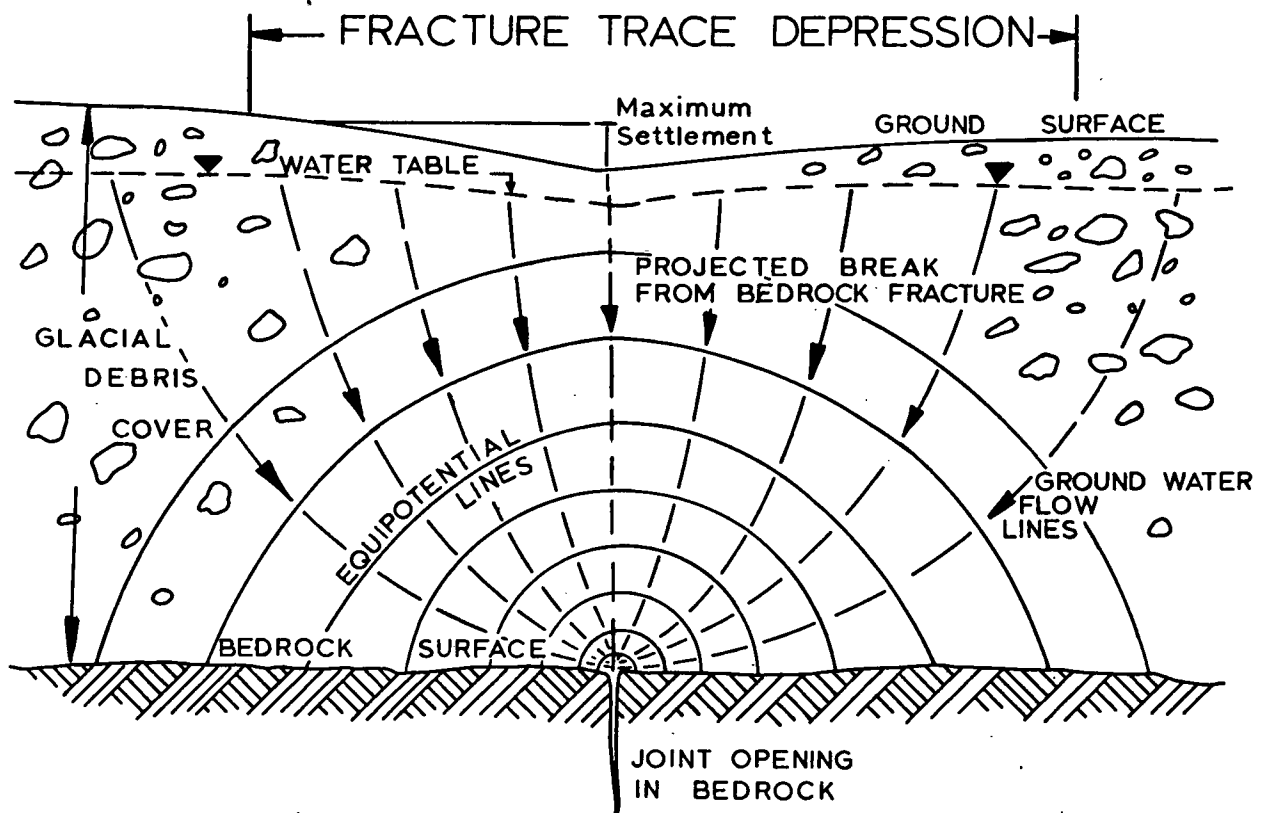


FIGURE 2. Flow of subsurface water through glacial debris cover into a narrow fracture opening in the underlying bedrock. The area of settlement is also shown, caused by the loss of overburden material through prolonged leaching by ground water movement, creating a fracture trace depression. (Modified after Mollard, 1957).

### 3.0 NASA REMOTE SENSOR DATA

In addition to the ERTS-1 imagery, other NASA imagery of portions of the test area is being utilized. This imagery includes high-altitude color infrared photography acquired in 1971 and low altitude color, color infrared photography and radar imagery acquired in support of this investigation.

#### 3.1 High Altitude Color Infrared Photography

Color infrared photography at a scale of 1:120,000 was acquired over most of the test area in 1971 as part of the Corn Blight Project. Mid-May (Mission 166), June (Mission 173), and August (Mission 178) coverage has been acquired for a major portion of the test area.

#### 3.2 Radar Imagery

Low angle<sup>1/</sup> side-looking radar imagery was provided by NASA (Mission 210, Test Site 318) in support of the investigation. Both synthetic and real aperture imagery was acquired in VV and VH polarizations. Flight lines extended from Terre Haute to Evansville in areas where mine subsidence is prevalent.

#### 3.3 Low Altitude Color and Color Infrared Photography

As part of Mission 210, 1:20,000 scale color and color infrared photography in 9 1/2 X 9 1/2" format was acquired over the centerlines of the radar-imaged areas. Both types of photography are of excellent quality and contain useful fracture information in addition to data concerning surface mining and its effect on the environment.

#### 3.4 ERTS-1 Imagery

##### 3.4.1 Data Quality

Completely cloud-free ERTS imagery has yet to be received over the entire test area; however, several frames, primarily in the southern portion of the area, are largely cloud-free and were used to produce a 1:250,000 scale ERTS-image sheet. map of the area covered by the U.S.G.S. Vincennes map sheet.

The photometric quality of the imagery has sometimes been sufficiently poor so as to make it unusable. Some negatives are too dense to make acceptable prints without specialized commercial equipment. With good quality ERTS imagery fractures, fracture-controlled stream segments, and areas disturbed by surface mining can be readily identified.

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<sup>1/</sup> Depression angle of 8° from an altitude of 11,000 feet.

The elapsed time between overpass date and delivery date averages 60 days. Such delays have reduced the time available for prompt field checking and opportunities to report significant results. Evaluation has suffered from receipt of incomplete image sets in the formats specified by the Standing Order Form.

#### 4.0 IMAGERY ANALYSIS<sup>1/</sup>

##### 4.1 ERTS-1 Imagery

##### 4.1.1 Fracture Analysis Related to Mine Safety

ERTS-1 imagery is being analyzed for fracture lineaments and mined land information as a continuing effort. A preliminary fracture validation system has been devised by which suspect fractures will be judged by combined manual and electro-optical interpretation techniques.

An ERTS photomap has been prepared at a scale of 1:250,000 for the area corresponding to the Vincennes, Indiana 1° X 2° topographic sheet. Other such base maps will be prepared as suitable (cloud-free) imagery becomes available. The photomaps will be used for display of fracture data and will serve Indiana as a base for a mined land inventory system.

A qualitative assessment of the utility of individual spectral bands for investigation objectives has been made (Table 1). This assessment is based on a limited amount of imagery from the summer and fall seasons, and is subject to revision. Based on imagery received to date, MSS Bands 5 and 7 are the most useful for fracture discrimination purposes. This statement, however, should be qualified in that seasonal and environmental conditions are important factors influencing the ease of fracture discrimination.

Figures 3 and 4 are consecutive ERTS Band 5 images that show a flat, glacial drift-covered area which is intensely cultivated except for areas that are dissected by incised drainage systems. Two major vegetal categories occur in the area: short-lived cultivated crops and indigenous tree and bush cover along the streams. Crops mature and die (or become dormant) early in the fall, whereas the other vegetation remains green and vigorous for a somewhat longer period. Reflective differences between the dead and live vegetation is pronounced. ERTS-images acquired during this short-duration transitional period, emphasize drainage patterns which in many places are structurally controlled as evidenced by a pronounced linearity or en-echelon pattern. The investigators conclude that once-a season ERTS coverage for geological studies is not satisfactory for fracture analysis in temperate climates and that repetitive seasonal coverage is essential.

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<sup>1/</sup> The results described are based upon analysis of a limited quantity of ERTS-1 imagery acquired during the summer and fall, 1972. The results are therefore subject to modification and revision as the study proceeds.

TABLE 1. ERTS IMAGERY EVALUATION

ERTS MSS SPECTRAL BAND	4	5	6	7	Color Composite
Fracture Detection		XX	X	X	X
Mined Land Delineation			X	XX	X
Reclamation (vegetal cover)		X	X	XX	XX
Water Bodies (size and shape)			X	XX	X
Water Discloration and Turbidity	XX				XX
Physiographic Features		X	X	X	XX

X = fair to good

XX = good to excellent

Subjective evaluation of ERTS imagery for applications in fracture related mined hazards investigations and mined land studies. This evaluation is based upon observations of a limited amount of imagery acquired during months of high plant vigor. Good coverage was available during the period of plant vigor decline, i.e., late September through early November. Some of the above assessments of value are based upon transient environmental conditions and may be invalid for other portions of the year.



Figure 3. ERTS-1 (1088-16050-5, 19 October 72) of East Central Illinois-West Central Indiana as imaged in the red (600-700nm) portion of the electro-magnetic spectrum. Two prominent structural trends are indicated; a N 10°-15° W and a secondary trend of N 70°-80° E. The localized east-west trending drainage pattern southeast of Terre Haute requires further investigation, and may prove of particular interest to coal mine safety studies. This area is in the northern portion of the Indiana coal field contains many surface and underground coal mines.

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Figure 3

Figure 4. ERTS-1 Image (1070-16050-5, 1 October 72) of the central portion of the Illinois structural basin imaged in the 600-700 nm portion of the spectrum.

The area shown on this image lies immediately south of Figure 3, and reveals sharply-pronounced fracture trends. This image reveals a great quantity of new fracture or lineament data for the central portion of the Illinois structural basin which may have significance for mineral exploration in the area. A predominant trend of about N 30° E is evident near the image center and numerous secondary trends can be identified. The deepest portion of the Illinois structural basin is located 30-40 miles south-southeast of the image center. Dead agricultural vegetation images lighter in tone than the green (dark toned) vegetation along the natural drainage systems. In this way, the structurally controlled drainage courses are emphasized.

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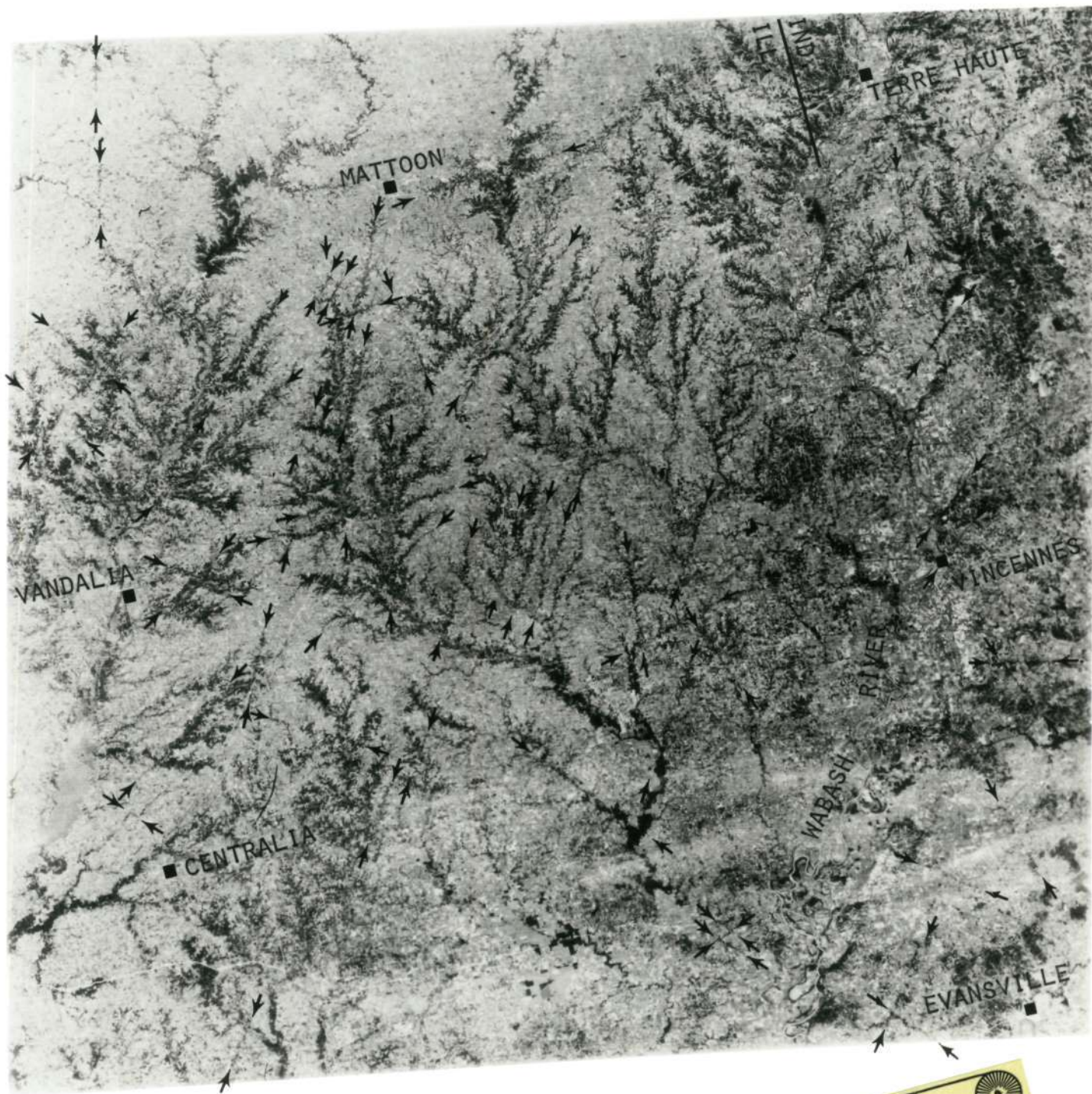


Figure 4

Another aspect of seasonal (environmental) influences on fracture detection is illustrated in Figure 5. Indiana lies in a temperate climatic zone that receives substantial rainfall and is vegetation-covered most of the year. Band 7 (near infrared) imagery acquired during the growing season displays relatively uniform vegetative tones, and few surface details but water courses and water bodies. With vegetation die-back, Band 7 provides greater detail more nearly resembling Band 5 imagery. The Band 7 image acquired on 5 November 1972 (Figure 5) reveals a lack of highly reflective vegetation which when combined with low sun angle, emphasizes the intricate fracture pattern in limestone upland areas. The investigators conclude that multiband ERTS coverage has already proven of significant value for fracture detection, and anticipate that bands 5 and 7 will most contribute on an annual basis for fracture identification purposes.

#### 4.1.2 Mining and the Environment

ERTS imagery is of value for monitoring of surface mining activities as demonstrated by the Mined Land Inventory map (Figure 6) prepared from ERTS imagery. Seasonal conditions influence the amount of information which can be obtained; for example, Band 7 imagery acquired during the growing season in Indiana sharply contrasts nearly bare disturbed areas from nearby undisturbed terrain.

The mined land inventory map prepared at 1:250,000 scale shows the status of surface mining in southwest Indiana as of August 25, 1972. The land mined as of 1968 was taken from Regional Geologic Map No. 3 prepared by the Indiana Geological Survey. Recently mined (black) area data was obtained from Band 7 ERTS image numbers 1033-15591 and 1033-15594. The original imagery (Figure 7) contains additional details related to mining and the environment, e.g. mining-produced water bodies, large haul roads, large refuse (gob) piles and slurry ponds.

Bare ground can be readily recognized; the investigators judge that with repetitive ERTS coverage, new mining of only a few acres can be identified.

In response to new reclamation laws, many companies find it more profitable to rapidly return mined lands to crop pasture rather than forests. In past years, mined lands were left relatively bare for long periods i.e. until obscured by maturing trees. At the present time, however, many mine lands are difficult to identify from nearby agricultural areas within several months after mining; such rapid land changes require repetitive synoptic coverage which ERTS provides.

The investigators conclude that area mined lands inventory and assessments of the degree of reclamation is an immediate application of repetitive ERTS imagery.

#### 4.2 High-Altitude Color Infrared Photography

Fracture information is also being acquired from 1:120,000 scale, color infrared photography. This photography provides an area overview at a scale intermediate between ERTS and low-altitude aircraft photography. Fracture information in both drift and non-drift covered areas is being obtained which complements ERTS-1 (and low altitude aircraft) imagery.

Figure 5. ERTS-1 image (1105-15595-7, 5 November 72) of Southwest Indiana

This ERTS-1, Band 7 (800-1100nm) image was acquired during a period when deciduous vegetation was dead or dormant. Lineaments are detectable because of enhanced surface relief produced by a combination of factors including low sun angle, vegetative tonal variations and soil moisture differences. The physiographic provinces of southwestern Indiana are readily identifiable on this image. The southerly trending Norman Upland between Bloomington and Columbus is highly dissected and largely uncultivated. The Crawford Upland west of Bloomington is separated from the Norman Upland by the highly cultivated Mitchell Plain. It is in turn, bounded on the west by the broad Wabash Lowland in which most of Indiana's coal occurs. The till free uplands are highly dissected and many of the stream valleys reveal a preferred orientation predominantly N 40°-50°E and N 60°W which reflect fracture zones.



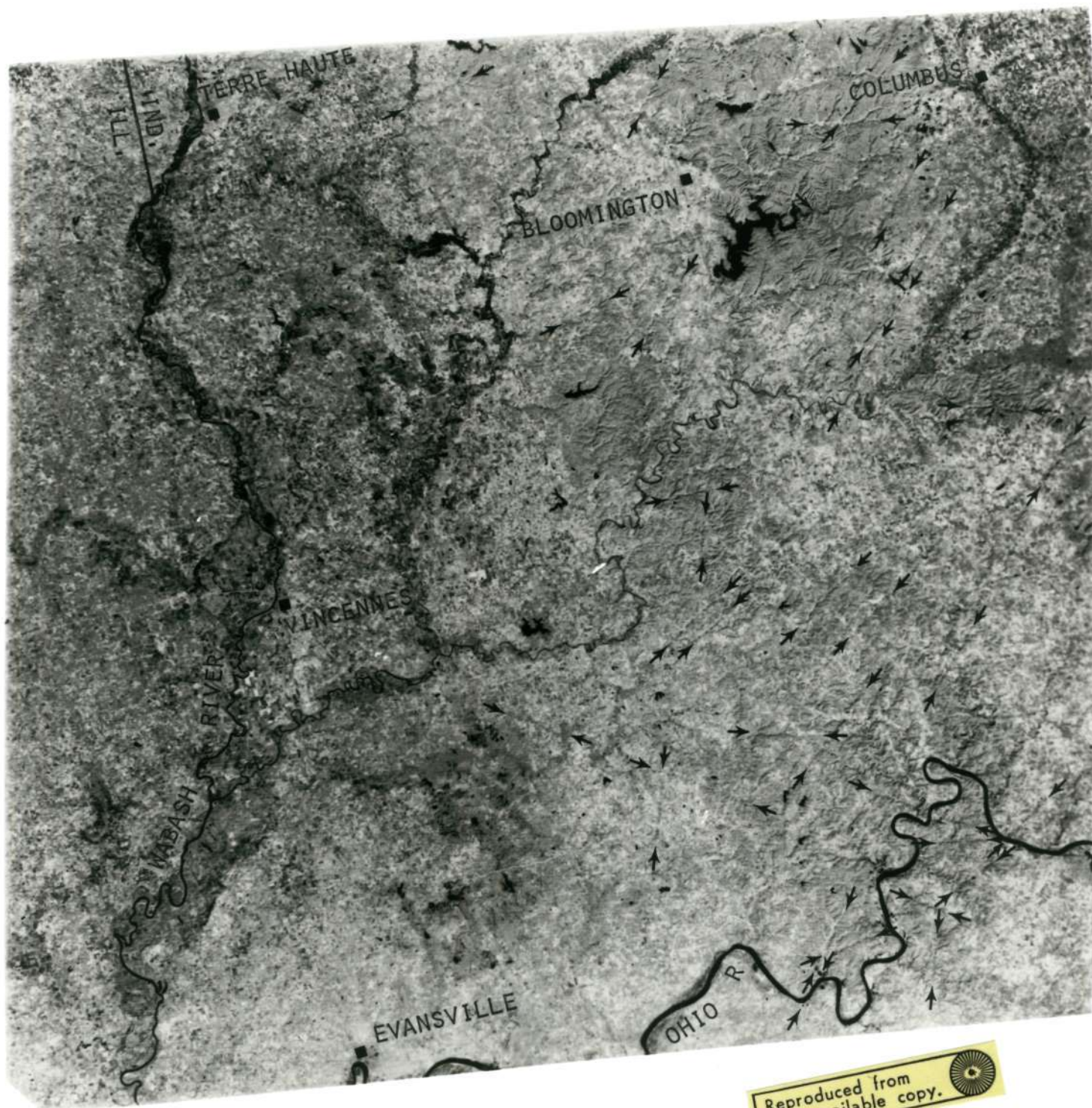




Figure 5

**ERTS-1  
MINED LAND INVENTORY MAP  
PIKE, WARRICK AND GIBSON COS., IND.**

 Area strip mined prior to 1968. (Data from the Indiana Geological Survey Regional Geologic Map No. 3)

 Areas mined since 1968. Mapped from ERTS-1 imagery.

PREPARED BY EARTH SATELLITE CORPORATION  
AND THE INDIANA GEOLOGICAL SURVEY  
UNDER NASA CONTRACT NAS5-21795

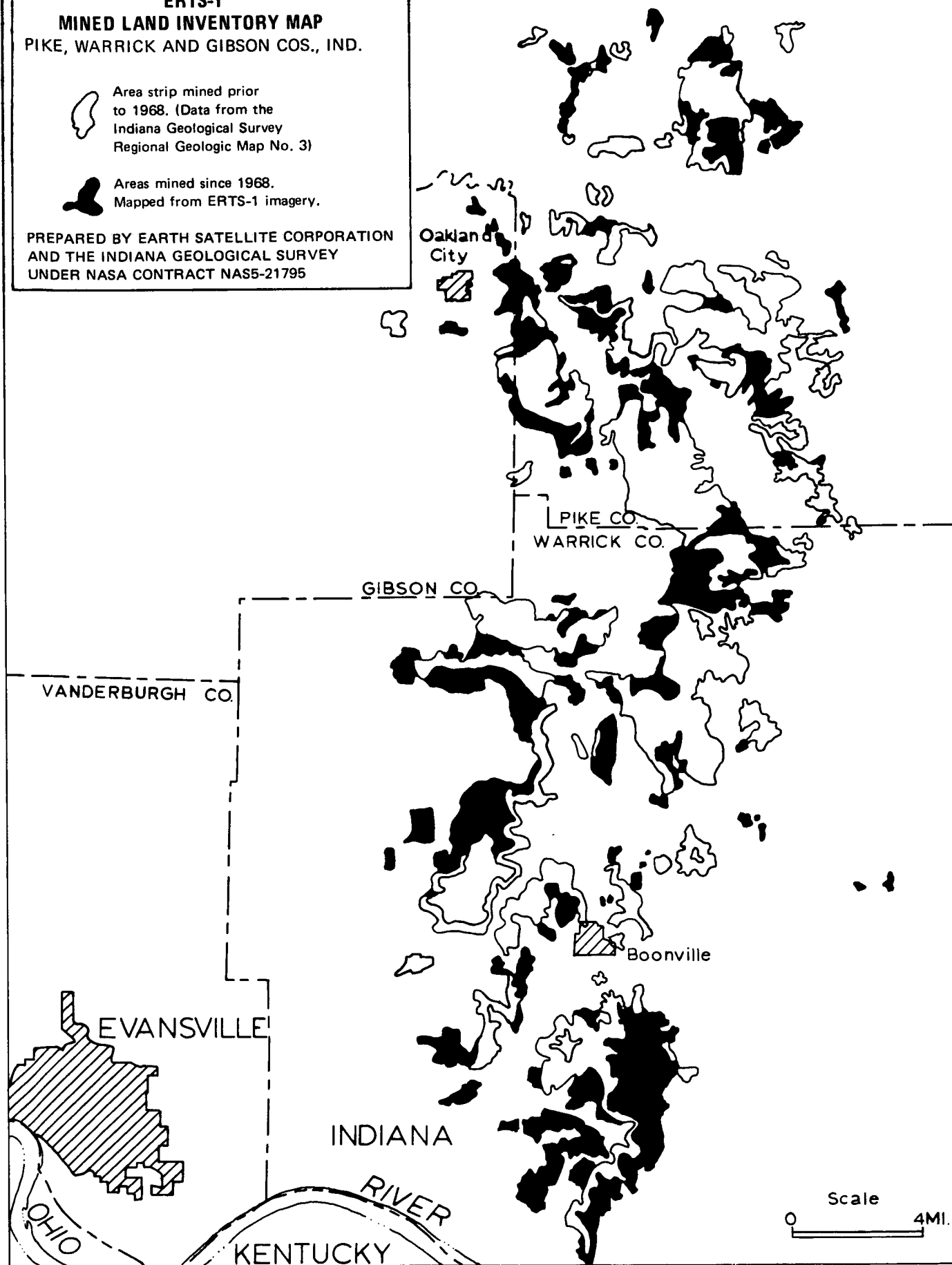


FIGURE 6 22



Figure 7. Band 7 ERTS image of approximate area and scale of mined land map.

On this image the mined lands of irregular outline appear in darker tones than the surrounding farmlands. Refuse piles and slurry ponds which are closely associated with the mined areas appear nearly black in tone but can be easily confused with normal water bodies. The highwalls along the leading edges of the mined areas and the larger haul roads appear as darker linear features. Cloud cover is evident along the left side of the image.

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Analysis of this small-scale photography is 90% completed. Photography from three different missions (May, June and August) has been analyzed to assess which would yield the greatest quantity of fracture data. The May flight (May 14, 1971) proved of greatest utility because vegetative cover is limited and subtle soil variations (tones) indicative of buried bedrock fractures can be seen. Vegetative growth present at the time of the June and August photography seriously handicapped fracture analysis.

Studies of the relative abundance of mapped fractures in non-glaciated areas versus the Illinoian and Wisconsin drift-covered areas of Indiana suggest that considerably more fractures can be detected in the glaciated than non-glaciated areas<sup>1/</sup> and that the Wisconsin drift exhibited a greater number of fracture traces than the Illinoian drift. This situation has yet to be explained.

Fractures which were identified using high-altitude color infrared photography and which intersected bedrock exposures in abandoned strip mines showed a close correspondence following field checking. Other fractures mapped in the proximity of operating surface and underground coal mines will provide additional opportunities for confirmatory field checking.

Studies to establish the relationships between sites of mining fatalities and ERTS/aircraft-derived fractures information has commenced. Particular attention is being given to a recent fatality (Figure 8) caused by a roof fall at the King Station Coal Corporation mine near Princeton, Indiana. A supplementary black and white 1:32,000 scale enlargement of color infrared photograph (Figure 9) was intensively analyzed and several significant fractures crossing the area reported to IGS as the location of the mine roof fall were identified.

The King Station mine has been in operation for over 20 years, and large areas have been mined using the room and pillar methods. Roof fall problems and subsidence have occurred during past operations in this mine. Several prominent linear patterns expressed as soil (tonal) anomalies or straight stream segments have been mapped in and around the mined area. Intersecting fracture systems in the vicinity of the accident site are of particular interest as they represent probable zones of structural weakness. Additional information is needed to precisely locate the roof fall of November 8 and a positive correlation is not possible at this time.

A preliminary analysis of the fracture data at the King Station Mine is shown in Figure 10. The fracture rosette graphically shows major fracture trends as approximately N7°W and N50°E. The histogram illustrates by section the relative prominence (linear measure) of fractures mapped. Section 22, in which the fatality occurred, has the greatest fracture density. This is closely followed by sections 24, 34 and 35. Although yet to be confirmed in consultation with the Coal Company, EarthSat and IGS anticipate that the latter sections, have experienced relatively extensive roof problems.

High-altitude imagery aircraft is a useful complement to ERTS-1 for determination of new surface mining operations and strip mined land inventories. Studies of suspected mine subsidence can best be conducted using 1:120,000 scale or larger imagery. Mine subsidence studies will be discussed in greater detail in Phase III of the investigation.

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<sup>1/</sup>This observation is restricted to photographic analysis of the physiographic area known as the Wabash Lowlands in which the Indiana coal field occurs. Upland areas of Indiana supported by limestone formations, were not studied.



## Coal miner killed, 3 injured in cave-in

Special to The Courier

PRINCETON, Ind. — One coal miner was killed and three others injured Wednesday when a portion of the roof at the King Station Coal Corp. mine three miles south of Princeton caved in, officials said.

Norman Rinsch, 53, of Edwardsport, was crushed beneath the rock mass in the 8:30 a.m. accident.

In critical condition at Gibson General Hospital is Hershel Howard, 39, of Sullivan; in fair condition, Harry Lovell, 43, of Princeton.

Robert Estep, a service representative from Joy Manufacturing Co. of Indianapolis — a mining machinery firm — was treated and released for minor injuries.

A spokesman indicated the four men were riding in a jeep-like underground vehicle when the roof section which was supported by several ceiling braces gave way.

A company official said a full investigation is being made by representatives from the State and Federal Bureau of Mines, company officials, and United Mine Workers Local 5534.

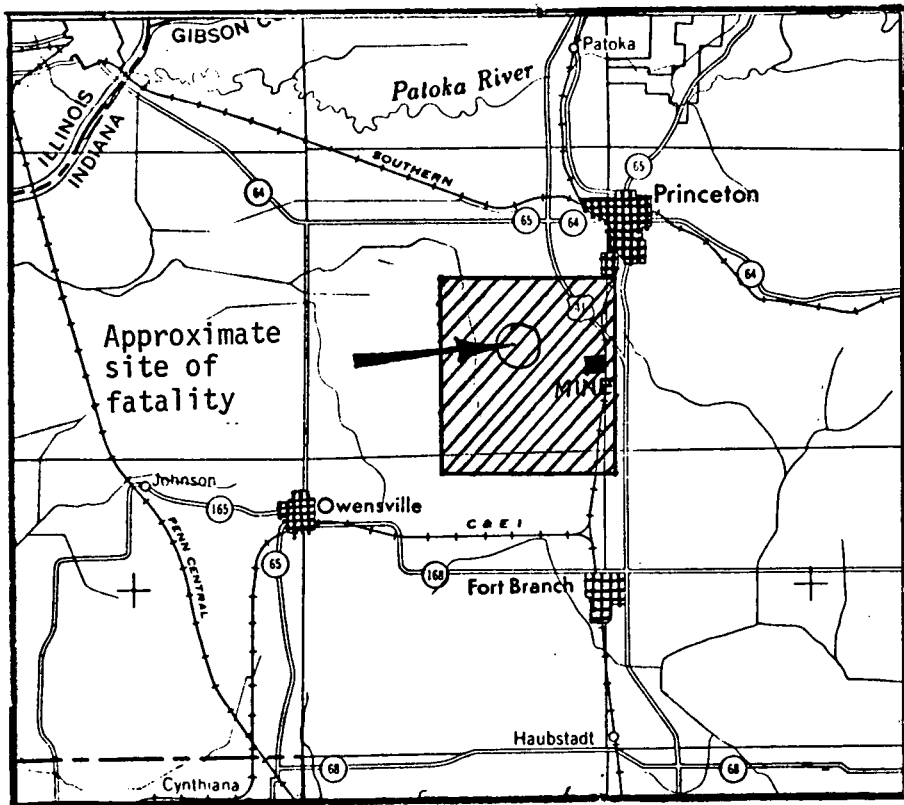


FIGURE 8. Newspaper story and map showing location of King Station Coal Mine accident. Shading indicates area covered by aerial photograph of the mined area.




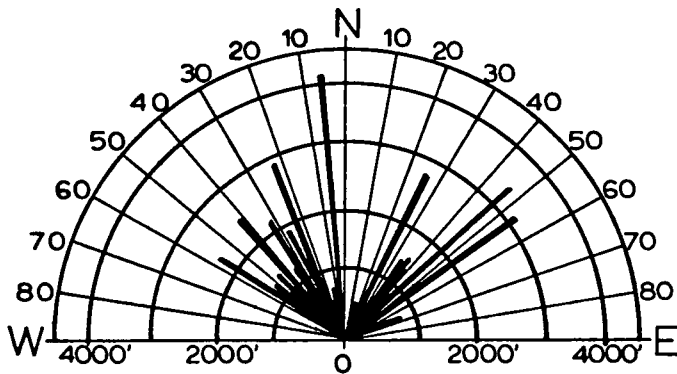
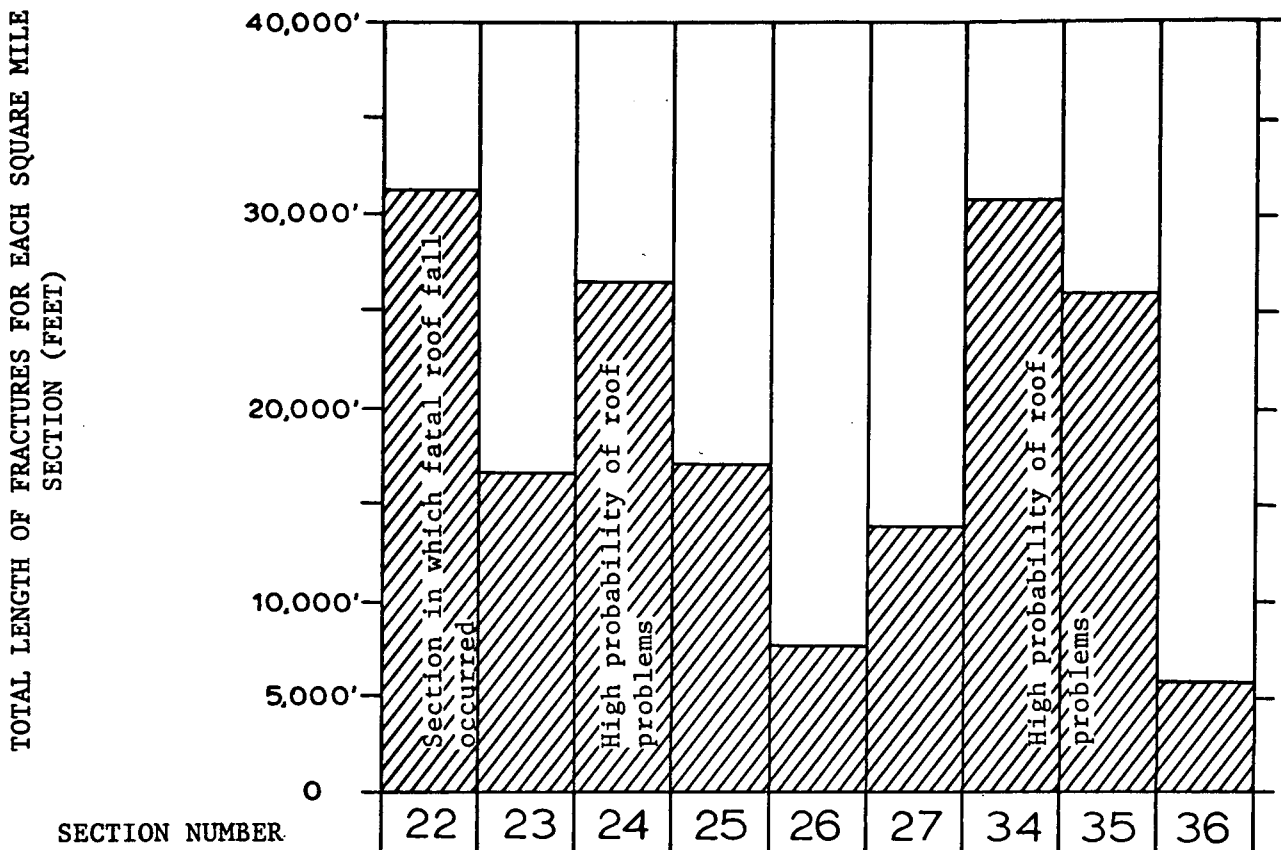
Reproduced from  
best available copy. 

Figure 9. Mined area configuration (1966) of King Station Mine, with lineament (fracture) annotations.

FIGURE 10



Rose diagram showing the direction and lengths for all fractures mapped on the aerial photograph of the King's Mine Area. These data will be related to mine drift orientation at a later date.

22	23	24
27	26	25
34	35	36

Index to section numbers used in the above graph.

### 4.3 Radar Imagery

Radar Imagery was analyzed for evidence of mine subsidence and major fractures. Although some apparently fracture-controlled straight stream segments were identified, the resolution of the imagery proved to be too poor to detect fractures and the subtle topographic variations associated with mine subsidence.

### 4.4 Low Altitude Color and Color Infrared Photography

Color and color infrared photography at 1:20,000 scale was studied to identify mine subsidence and to detect short (probably secondary) fracture systems. Fracture analysis using this imagery emphasized the utility of an integrated multilevel/multiband approach to fracture detection i.e. lineaments identifiable using 1:20,000 scale imagery are not always detectable on the 1:120,000 scale imagery are not always detectable on the 1:120,000 photography. Conversely, lineaments found on the small scale photography often have too subtle a signature to be detected using large scale photography.

## 5.0 SIGNIFICANT RESULTS

The most significant result of IGS-EarthSat studies to date is a demonstration of the special value of repetitive ERTS-1 multiband coverage for detecting previously unknown fracture lineaments despite the presence of a deep glacial overburden. The Illinois Basin is largely covered with glacial drift and few rock outcrops are present. Most of the limited knowledge of the structure in the area has been derived from mining, drilling and geophysical surveys. General structural trends were known at the time of ERTS-1 launch but the presence of pronounced major fracture systems in the central part of the basin was unsuspected. A contribution to the geological understanding Illinois and Indiana has been made. This data may not only contribute to improved mine safety but have economic significance in some areas of southeast Illinois. High-altitude color infrared photography at 1:120,000 scale is also providing significant fracture data in the glacial drift covered areas. Preliminary analysis suggests a tentative correlation between ERTS/aircraft identified fractures and mine fatalities.

Analysis of ERTS imagery has provided useful information to the State of Indiana concerning surface mined lands. The contrast between healthy vegetation and bare ground as imaged by Band 7 is sharp and substantial detail can be obtained concerning the extent of disturbed lands, associated water bodies, large haul roads and extent of mined lands revegetation. During the growing season, bare ground is readily identifiable and changes in mine configuration of only a few acres can be made. The repetitive image acquisition capability of ERTS makes a national mined lands surface-mining monitoring program a distinct possibility.

The feasibility of acquiring fracture data under difficult physical conditions i.e. in areas of intense agriculture and deep glacial drift has been demonstrated and will benefit geological studies nationally. The likelihood of applying ERTS derived fracture data to improve coal mine safety in the entire Illinois Basin is suggested from studies conducted in Indiana.

## 6.0 NEW TECHNOLOGY

To date, no new technology, processes have been devised from this investigation.

## 7.0 PROGRAM FOR NEXT REPORTING PERIOD

The specific tasks planned for the next reporting interval are as follows:

- Institute Data Analysis Plan procedures following NASA approval.
- Continue final report preparations
- Continue detailed analysis of NASA aircraft coverage for fracture data and evidence of mine subsidence
- Continue detailed analysis of ERTS-1 imagery noting seasonal changes and amount of data interpretable from the different spectral bands using a fracture validation system
- Continue collection of fracture data from surface and subsurface field measurements.
- Consolidate fracture data derived from ERTS, Corn Blight, NASA under-flight imagery, and field observations into a fracture map for the Indiana coal field
- Acquire and analyze all available high-resolution radar imagery flown over the Indiana test sites from released Air Force files.
- Establish a correlation between zones and high concentration of fractures and mine accidents
- Establish criteria for determining hazardous areas
- Visit selected surface and underground mine operators to ensure the utility of hazards data and establish format(s) for mine safety products
- Delimit hazardous zones in active and future coal mining areas in map form for coal industry and State use

## 8.0 CONCLUSIONS

The Indiana Geological Survey and EarthSat conclude that repetitive ERTS-1 imagery is a useful tool for mapping regional fractures in areas covered by thick glacial drift, and for monitoring recently mined lands in coal-producing areas. Fracture data, previously unavailable for mine safety and related geological studies in Indiana are now available.

Seasonally dependent MSS Bands 5 and 7 imagery is most useful for fracture detection and Band 7 is best for regional mined land inventories. Summer should prove the best season for ERTS imagery acquisition for mapping mined lands as it provides the greatest contrast between vegetated land and bare



ground. It is anticipated that ERTS imagery acquired in the fall and spring will be best for fracture detection because the fields are largely fallow and bare and vegetational differences are pronounced. This latter criteria also applies to high-altitude color infrared photography.

There appears to be a good correlation between fractures mapped on high-altitude color infrared photography and fractures measured in the field.

Mined land investigations with ERTS imagery show promise of rapidly providing useful information to state or federal agencies. Changes of only a few acres in the configuration of area-surface-mined lands appears realistic with comparative analysis of time-lapse imagery.

The feasibility of acquiring fracture data under difficult physical conditions, i.e. in areas of intense agricultural activity and areas of deep glacial drift has been demonstrated and will broadly benefit geological mapping programs. The likelihood of applying ERTS-derived fracture data to improve coal mine safety in the entire Illinois Basin appears practical from the current studies being conducted in Indiana.

## 9.0 RECOMMENDATIONS

Fracture detection in the drift covered areas of the Illinois Basin was made possible by repetitive monitoring of subtle transient conditions, e.g. autumn vegetation dieback. This emphasizes the need for careful study of all ERTS coverage as acquired. Geological investigators should not be constrained to one image set per season. Also, cloud cover requirements should be considered carefully. The single ERTS image acquired during the period of high plant vigor, which permitted the preparation of the Mined Land Inventory map, was correctly classified by NASA as having over 50% cloud cover; however, the area of prime interest to this experiment was essentially cloud free. From these experiences the authors recommend that full-season ERTS coverage be provided for geological investigations such as that being conducted in Indiana, the success of which depend upon recognition of subtle and often transient phenomena.

## APPENDIX A

## GLOSSARY OF GEOLOGICAL TERMS IN THIS REPORT

**EASTERN INTERIOR COAL BASIN** - The portion of the Illinois Basin in which coal beds were deposited.

**FAULT** - A fracture surface or zone in rock along which appreciable displacement has taken place.

**FRACTURE** - A surface along which loss of cohesion has taken place, i.e. a general term for any break in a rock. A fracture along which no displacement has occurred is a joint, while one along which there has been displacement is a fault.

**FRACTURE TRACE** - A natural linear feature which is the surface expression of a fracture in the bedrock.

**GLACIAL DRIFT** - A general term for any material that has been transported by glaciers.

**GLACIAL TILL** - A heterogeneous mixture of unconsolidated and unstratified clay, sand, and gravel deposited directly beneath a glacier without reworking by water glacial meltwaters.

**HIGHWALL** - The unexcavated face of exposed overburden and coal in a strip mine, exposed along the last trench excavated.

**ILLINOIAN** - Pertaining to the third glacial stage of the Pleistocene Epoch in North America, beginning about 115,000 years ago.

**ILLINOIS BASIN** - A major sedimentary basin centered in southeastern Illinois and including most of the state of Illinois, southwestern Indiana, and western Kentucky. Basin strata range from Cambrian to Pennsylvanian in age.

**JOINT** - A surface of actual fracture or parting in a rock without displacement of either side relative to the other.

**LINEAMENT** - A alignment of given features on a regional scale generally judged to reflect geologic structure. In this report the term is generally used to indicate what are unconfirmed (unvalidated) expressions of a buried joints or faults.

**OVERBURDEN** - Barren rock material overlying a mineral deposit and which must be removed prior to mining.

**VALIDATION** - A deductive system for giving increasing weight to a lineament using manual and/or electrophotical techniques.

**WISCONSIN** - Pertaining to the fourth glacial stage of the Pleistocene Epoch of North America beginning about 85,000 years ago.

## APPENDIX B

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## APPENDIX C



# TASK STATUS REPORT

TASK	STATUS	COMMENTS	
PHASE I PRELAUNCH PREPARATION			
1.0	ESTABLISH TECHNICAL INTERFACE WITH NDPF	COMPLETED	Meetings held with the scientific and technical monitors; contact with NDPF made.
2.0	PREPARE EXPERIMENT FACILITIES AT INDIANA		
2.1	ASSEMBLE EQUIPMENT AT IGS		IGS has established data storage facilities and acquired necessary equipment for field use of ERTS imagery.
2.2	EXPERIMENT BRIEFING	COMPLETED	Earth Satellite Corp. scientists briefed IGS and Indiana Coal Association personnel on the scope of the experiment and application of small scale photography and imagery to coal mining and industry problems.
2.3	COMPILE TEST AREA DATA	COMPLETED	Reference materials (e.g. maps, bulletins etc.) related to area geology and fracture distribution, and were assembled. Copies were provided to EarthSat.
2.4	RECONNAIS- SANCE VIST TO TEST AREA.	COMPLETED	A field trip was made by the co-investigators (ERTS image analysts) and the Principal Investigator to better appreciate fracture detection and measurement problems (Active coal mining operations were visited in Southern Indiana).
3.0	SELECT BASE MAP WORKING SCALE(S)	COMPLETED	The base map scale was established following a first look at ERTS imagery. A scale of 1:250,000 was selected.

# TASK STATUS REPORT

Contract # NAS5-21795

TASK		STATUS	COMMENTS
PHASE I (con't.)			
4.0	PREPARE MINING HAZARDS COLLATERAL DATA		
4.1	FAULT AND FRACTURE DATA	COMPLETED	Data on known faults were assembled and plotted on a regional base (line) map.
4.2	REPORTS AND MINE MAPS	UNDERWAY	Maps of underground mines are being evaluated by the Principal Investigator for indications of zones of rock weakness.
4.3	ZONES OF SUBSIDENCE	UNDERWAY	The detectability of mine subsidence at different scales of photography is being investigated by EarthSat.
4.4	FIELD DATA ON FRACTURES	UNDERWAY	IGS is conducting a continuing program of field fracture measurements in various portions of the Indiana Coal field. EarthSat will supplement these measurements if possible during field studies.
5.0	NASA UNDER-FLIGHT PROGRAM	COMPLETED	Requests for aircraft data have been submitted and one mission has been completed. EarthSat is coordinating overflight operations in close consultation with the Principal Investigator.
6.0	PRELIMINARY ASSESSMENT OF OPTICAL/ADP TECHNIQUES	COMPLETED	Various additive color, density slicing and edge enhancement techniques were investigated for applicability to fracture detection. Tests to automate some facets of the fracture mensuration process are continuing.

# TASK STATUS REPORT

Contract # NAS5-21795

TASK		STATUS	COMMENTS
PHASE I (con't.)			
7.0	INTERFACE WITH AREA COAL PRO- DUCERS	COMPLETED	Indiana Coal Association representative has been briefed on the program and the National Coal Association advised of the scope, intent and progress of the investigation. A formal written offer to brief NCA has been submitted. A sound working relationship with ICA is being maintained.

# TASK STATUS REPORT

Contract # NAS5-21795

TASK	STATUS	COMMENTS
PHASE II FIRST LOOK ANALYSIS		
<u>1.0</u>	RECONNAIS- SANCE ANALYSIS OF ERTS-1 IMAGERY	
1.1	PREPARE ERTS BASE MAP	UNDERWAY (NEARLY COMPLETE)
		An ERTS Imagery base map has been prepared at a scale of 1:250,000 for the area corresponding to the Vincennes, Indiana 1:250,000 scale topographic sheet. Others are being prepared as suitable (cloud free) imagery becomes available.
1.2	ANNOTATE BASE MAP WITH HAZARDS DATA	UNDERWAY
		Various data relating to coal mining hazards are being compiled on a base map. These data include incidents of rooffalls resulting in miner deaths, and evidence of changing mine drifts indicative of weak roof.
1.3	ERTS-1 IMAGERY ANALYSIS	UNDERWAY
		ERTS-1 imagery has been analyzed for fracture lineaments. This will be a continuing effort. A preliminary fracture validation system (see Task 2.0, continuing data analysis) is being tried.
1.4	RANK ERTS-1 SPECTRAL BANDS	COMPLETE
		An assessment of the utility of individual spectral bands for mine hazards investigations has been made by EarthSat. This is based on minimal imagery during the summer season and good coverage during the fall. This assessment will continue throughout the year. NOTE: Based on imagery to date, MSS Bands 5 and 7 appear to be most useful for fracture discrimination purposes.
<u>2.0</u>	PRELIMINARY COMPARISON OF ERTS-1 LINEAMENTS AND KNOWN HAZARDS DATA	UNDERWAY

# TASK STATUS REPORT

Contract # NAS5-21795

TASK		STATUS	COMMENTS
PHASE II (Con't.)			
<u>3.0</u>	INITIAL TESTING OF FRACTURE ANALYSIS TECHNIQUES		
3.1	MANUAL ANALYSIS	COMPLETE	The various standard manual analysis techniques apply equally well to ERTS imagery as to aerial photography. Scan line traces tend to obscure lineaments parallel to traces.
3.2	FILM SANDWICH	UNDERWAY	Standard film sandwich edge enhancement techniques have not been used extensively due to quality of ERTS negatives and due to availability of electro-optical instrumentation which accomplishes same results.
3.3	COMPUTER-ASSISTED	UNDERWAY	Fracture trace angle measurement and rosette plotting by computer are being programmed.
3.4	OPTICAL/ELECTRO-OPTICAL	UNDERWAY	Additive color and density slicing techniques are being used and tested.
4.0	GENERAL ANALYSIS OF NASA AIRCRAFT IMAGERY	COMPLETE	First analysis of the 1:120,000 scale color infrared (corn blight) photography as a complement to ERTS-1 imagery has been completed (additional work involving this lengthy process is planned in Phase III). Fracture lineaments are being identified using an experiment validation system; several photo-geologists are involved.
5.0	APPLY ERTS-1 AIRCRAFT IMAGERY TO PROBLEMS OF MINING AND ENVIRONMENT	NEARLY COMPLETE	Both ERTS-1 imagery and small scale photography are being applied to mapping geological lineaments. Other mined land (environmental) information is available from ERTS imagery. The extent of surface mining activity, resultant water bodies, large refuse piles and slurry ponds are being identified. An updated inventory of mined lands is being completed by IGS and EarthSat.

Contract # NAS5-21795

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# TASK STATUS REPORT

Contract # NAS5-21795

TASK		STATUS	COMMENTS
PHASE III CONTINUING DATA ANALYSIS			
1.0	MODIFY DATA ANALYSIS PROCEDURES	(AWAITING APPROVAL OF DATA ANALYSIS PLAN)	
2.0	ESTABLISH FRACTURE VALIDATION SYSTEM	UNDERWAY	A preliminary validation system has been prepared by EarthSat. Following testing, it will be revised and finalized.
3.0	CONDUCT DETAILED ANALYSIS OF NASA AERIAL PHOTOGRAPHY	UNDERWAY	High altitude (1:120,000) scale aerial photography now being analyzed. Reconnaissance analysis of data from NASA aircraft mission No. 210 has begun.
4.0	CONSOLIDATE FRACTURE DATA		
5.0	EVALUATE UNDERGROUND SURFACE MINE ACCIDENT DATA TO FRACTURE ZONES		Commenced in Phase II
6.0	DELIMIT HAZARDOUS ZONES IN ACTIVE/ ANTICIPATED COAL MINING AREAS		



# TASK STATUS REPORT

Contract # NAS5-21795

TASK		STATUS	COMMENTS
PHASE III (con't.)			
6.1	ESTABLISH CRITERIA FOR DETERMINING HAZARDOUS ZONES		
6.2	PREPARE MAP OF EVALUA- TION OF HAZARDOUS ZONES		
7.0	DEVELOP PROTOTYPE MINE SAFETY INFORMATION NETWORK		
7.1	VISIT MINE OPERATORS- DISCUSS APPLICATIONS OF HAZARDS DATA		
7.2	ESTABLISH FORMAT FOR MINE SAFETY DATA DISTRI- BUTION		
7.3	DISTRIBUTE MINE HAZARDS MAP.		

Contract # NAS5-21795

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## APPENDIX D

**ERTS IMAGE DESCRIPTOR FORM**  
(See Instructions on Back)

DATE JANUARY 5, 1973

PRINCIPAL INVESTIGATOR DR. CHARLES WIER

GSFC ST 355

ORGANIZATION INDIANA GEOLOGICAL SURVEY

NDPF USE ONLY

D \_\_\_\_\_

N \_\_\_\_\_

ID \_\_\_\_\_

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	River	Lake		
1033-15594 - 7,5,4	X	X		Smoke
1069-15594 - 7,6,5,4	X	X		Alluvial Plain
1051-15594 - 7,6,5,4	X	X		Strip Mines
				Lineament
				Meander
1033-15585 - 7,5,4	X	X		City (Indianapolis)
1069-15585 - 7,6,5,4	X	X		Lineaments
1033-15591 - 7,5,4	X	X		Alluvial Plain
1069-15591 - 7,6,5,4	X	X		Strip Mines
1051-15591 - 7,6,5,4	X	X		Lineament
				Meander
				Dendritic Drainage
				Fault
1086-15535 - 7,6,5,4	X	X		Alluvial Plain
1050-15535 - 7,6,5,4	X	X		Dendritic Drainage
				Fault
				Lineament
				Meander
1052-16050 - 7,6,5,4	X	X		Alluvial Plain
1034-16050 - 7,6,5,4				Strip Mines
1070-16050 - 7	X	X		Meander
1088-16050 - 7,6,5,4	X	X		Lineament
				Lake Deposits
	X	X		Moraine
1052-16043 - 7,6,5,4	X	X		Lineament
1070-16043 - 7,6,5,4	X	X		Strip Mines
				Moraine
				Lake Deposits

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO

ERTS USER SERVICES  
CODE 563  
BLDG 23 ROOM E413  
NASA GSFC  
GREENBELT, MD. 20771  
301-982-5406

## ERTS IMAGE DESCRIPTOR FORM

(See Instructions on Back)

DATE JANUARY 5, 1973PRINCIPAL INVESTIGATOR DR. CHARLES WIERGSFC ST 355ORGANIZATION INDIANA GEOLOGICAL SURVEY

NDPF USE ONLY

D \_\_\_\_\_

N \_\_\_\_\_

ID \_\_\_\_\_

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS*			DESCRIPTORS
	River	Lake		
1070-16052 - 7,6,5,4	X	X		Alluvial Plain
1088-16052 - 7,6,5,4	X	X		Coastal Plain
1088-16055 - 7,6,5,4	X	X		Fault
1052-16052 - 7,6,5,4	X	X		Lineament
1034-16052 - 7,6,5,4	X	X		Strip Mines
				Smoke
				Lake Deposits
1015-15593 - 7,6,5,4	X	X		See 15594 & 15591
1032-15532 - 7,6,5,4	X	X		See 15535
1086-15532 - 7,6,5,4	X	X		
1105-15595 - 7,6,5,4	X	X		Alluvial Plain
				Meander
				Moraine
				Lineament
				Fault
				Strip Mines
				Dendritic Drainage
1017-16100 - 7,6,5,4	X	X		Alluvial Plain
				Strip Mines
1086-15541 - 7,6,5,4	X	X		Dendritic Drainage
				Strip Mines
				Lineament
				Meander

\*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

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